



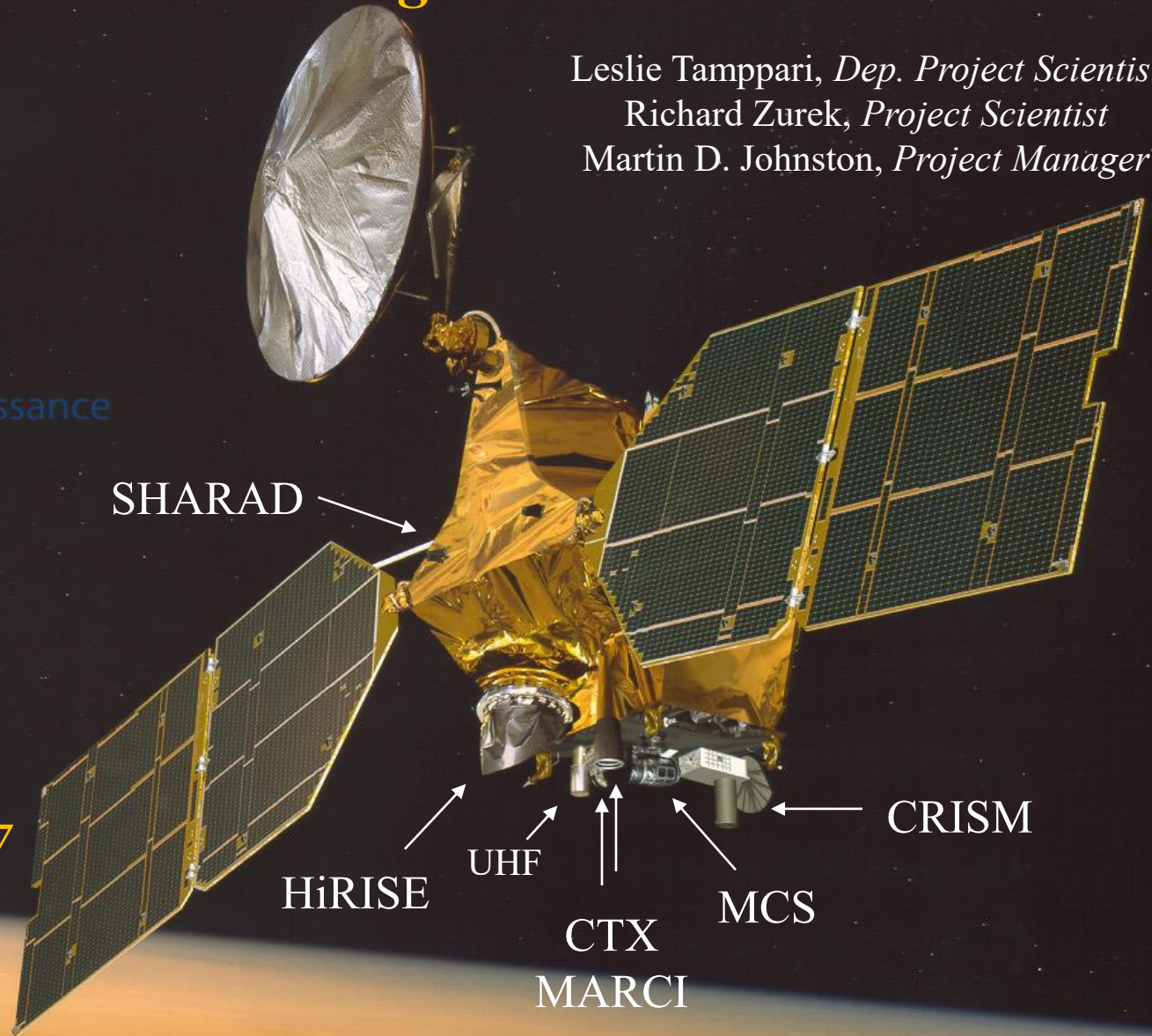
MRO: Continuing Discoveries at Mars

Leslie Tamppari, *Dep. Project Scientist*
Richard Zurek, *Project Scientist*
Martin D. Johnston, *Project Manager*

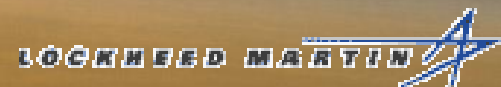
Mars
Reconnaissance
Orbiter

Presentation
to MEPAG

February 23, 2017



MIT



Jet Propulsion Laboratory/California Institute of Technology

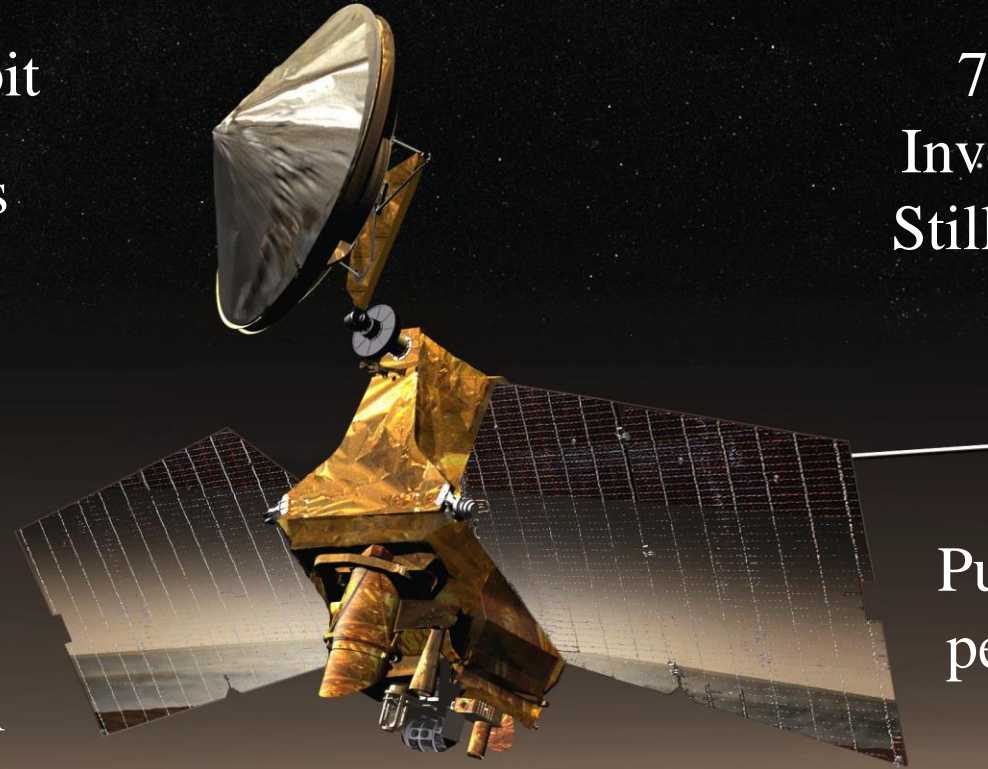
Rated “Excellent” in 2016 Planetary Mission Senior Review

11 Years in Orbit

~50,000 orbits

300 Tb of
Science Data
Returned

~200 kg of
Usable Fuel still
in the Tank



7 Science
Investigations
Still Returning
Data

~1000
Publications in
peer-reviewed
Journals

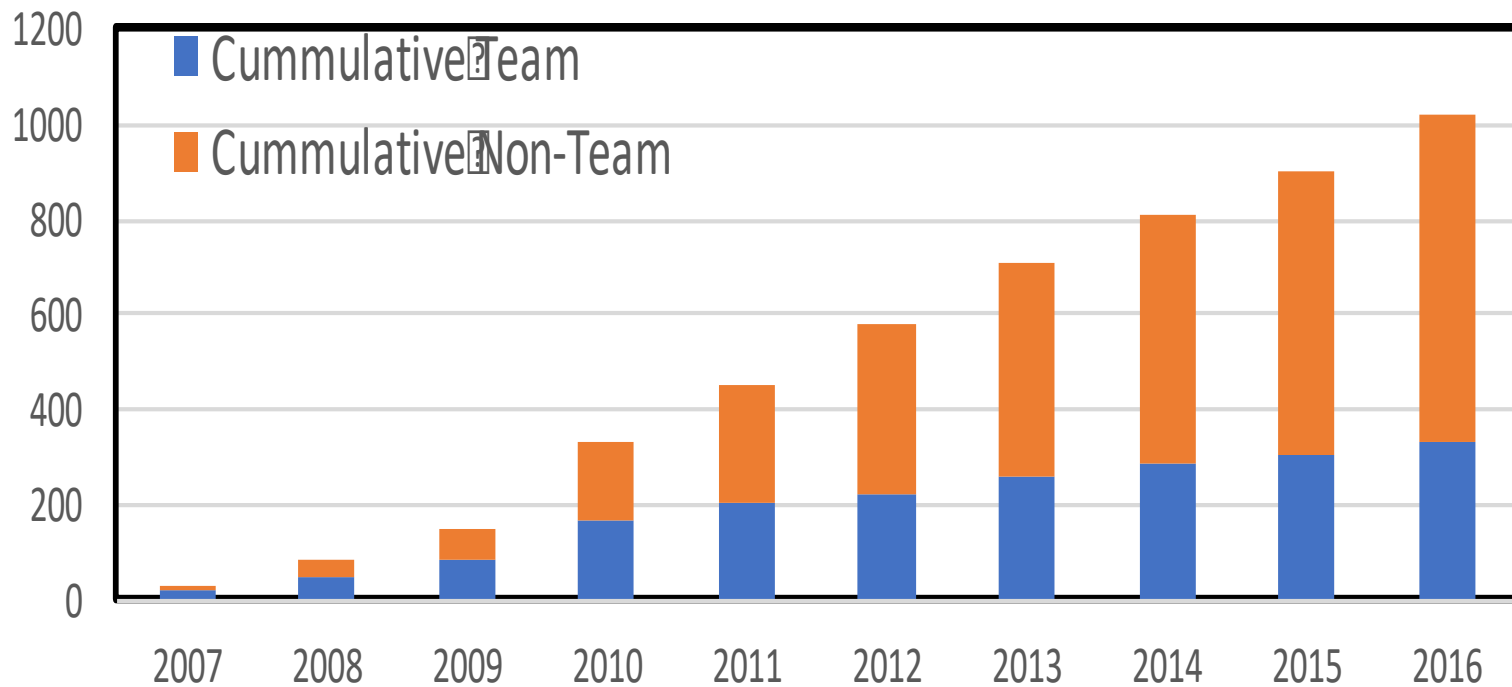
Mars Reconnaissance Orbiter

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Government sponsorship acknowledged.

Publications over time

MRO Cumulative Publications



MRO Science Investigations

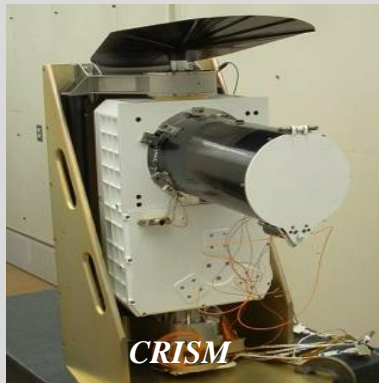
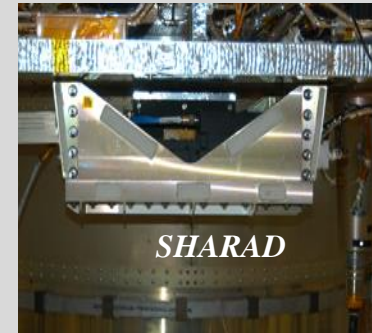


HiRISE

~49,000 images
(~5000 stereo)
~2.8% of Mars
RSL, Gullies,
Dunes, Polar Caps

SHARAD

~21,000 Observing Strips
Buried CO₂ Ice
Polar Cap Internal
Structure
Mid-latitude Ice



CRISM

~85% msp IR
~39% hsp IR
~76% hsp VNIR
Limb Scans
Ancient Aqueous Minerals
ATO's (6-12 m/pixel)

MCS

~150 M Soundings
~94% of 5.4 MYrs
Vert. Dust Profiles
Dust Storm Patterns
Tidal Structure
CO₂ snow and frost



CTX

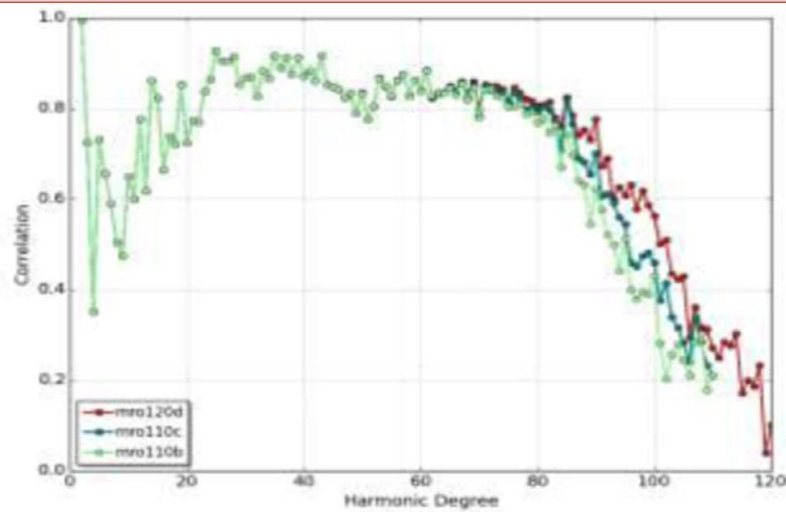
~92,000 images ~99% of
Mars 20% in dual
coverage
Stratigraphy
New Impacts

MARCI

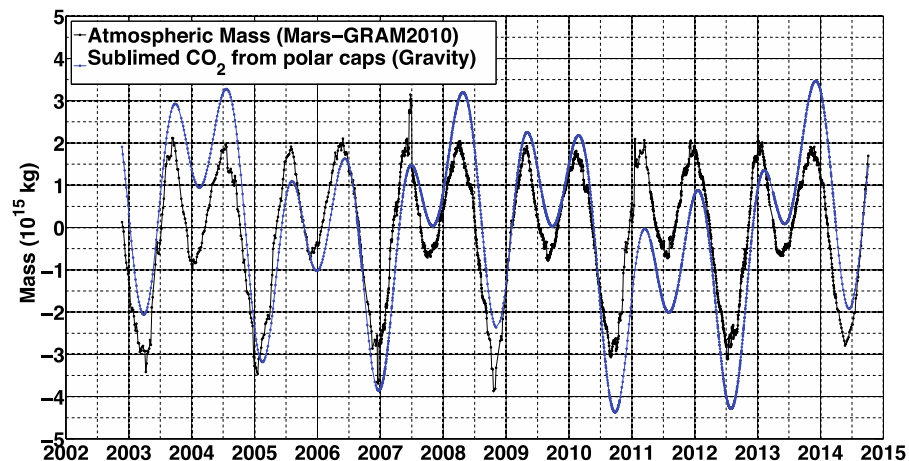
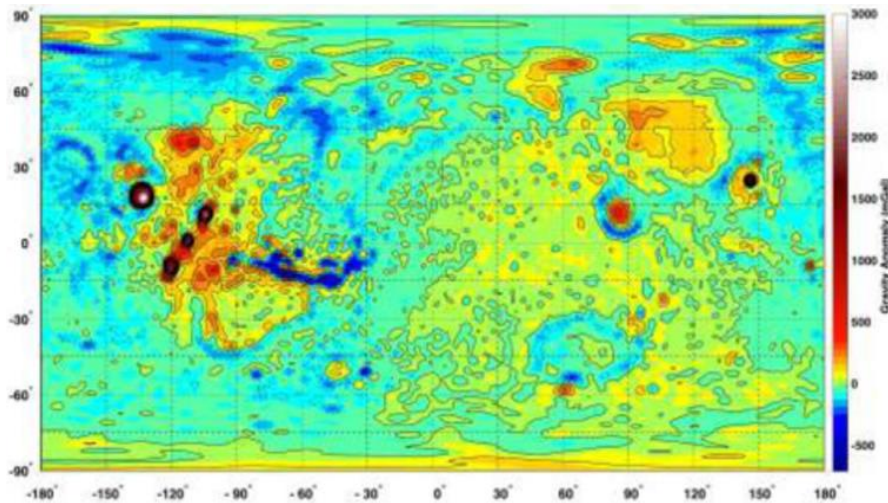
~47,000 images
5.4 Myrs
~3600 Daily Global Maps
Dust & Ice Clouds
Dust Storm Tracks



Static & Time-Varying Gravity Results

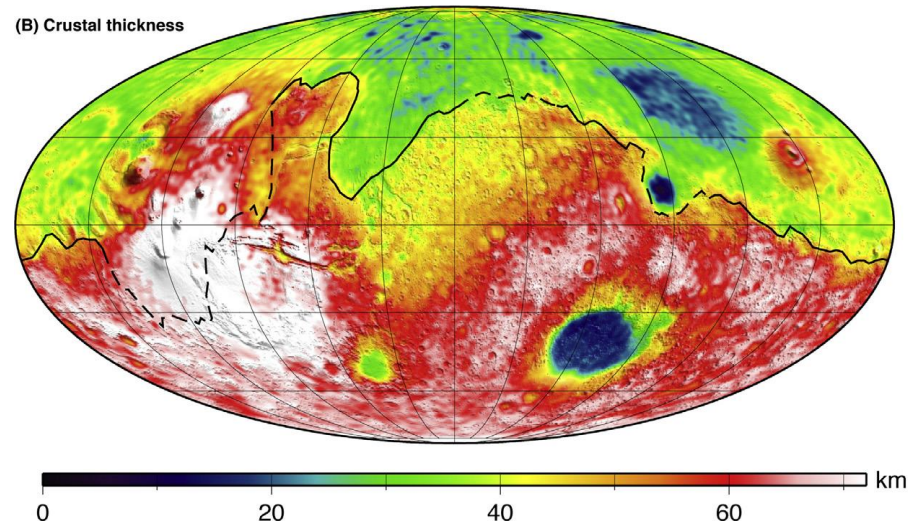


➡ *Konopliv et al. 2016*



➡ *Genova et al. 2016*

(B) Crustal thickness

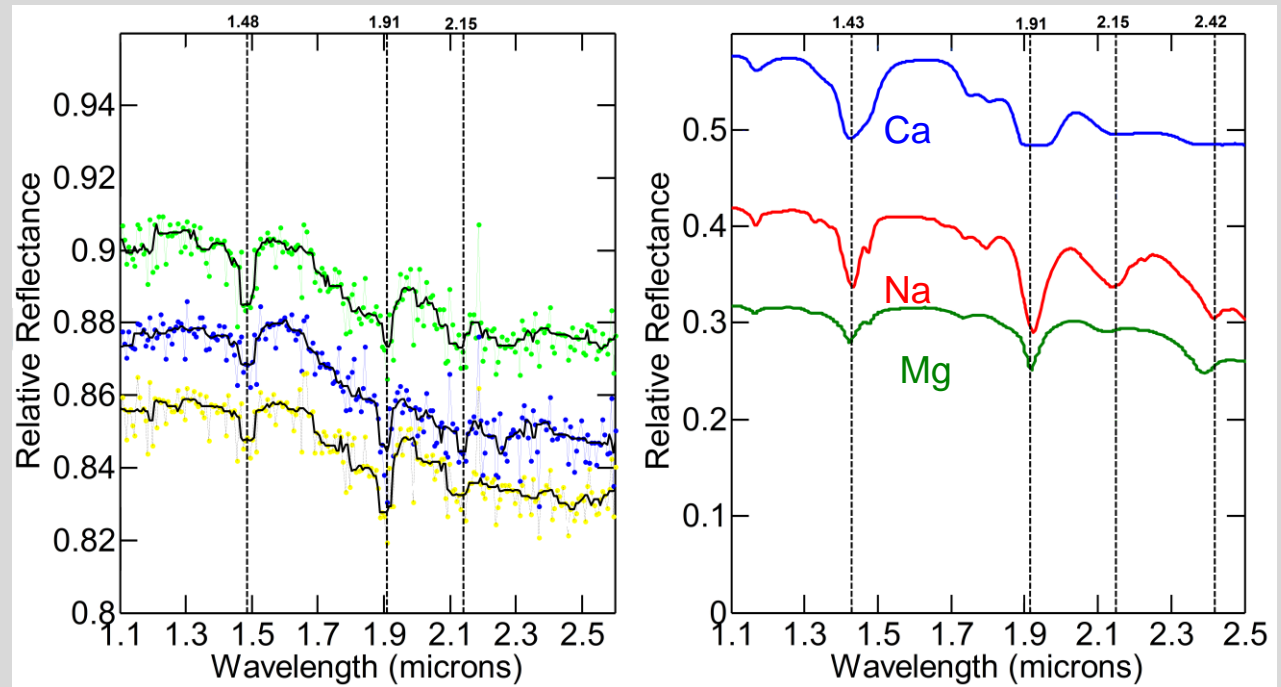
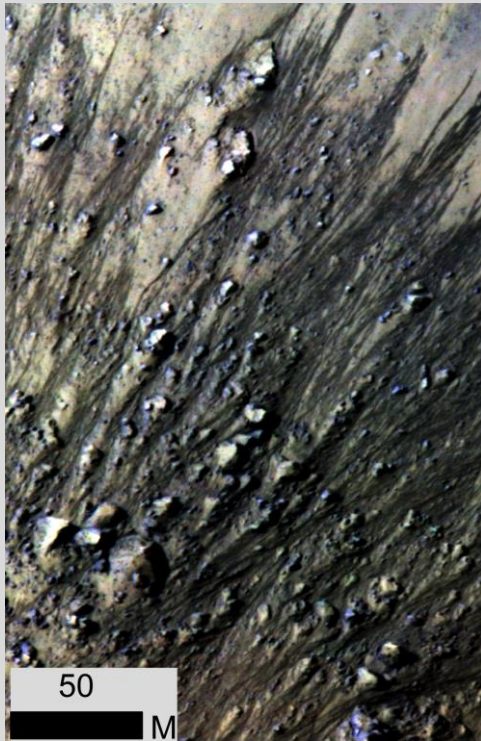


3rd Extended Mission Highlights

Oct. 2014 – Sept. 2016

- ***Highest resolution view of Oort cloud Comet C/2013 A1 Siding Spring***
- ***Assess Mars' past and present habitability***
 - Transition from wet/neutral to dry/acidic not as monotonic as previously thought;
 - Diverse conditions may have repeatedly occurred or even co-existed.
 - Hydrated perchlorates detected in the enigmatic Recurring Slope Lineae (RSL).
- ***Characterize the Mars atmosphere, present climate, and climate processes***
 - Doubled the detailed climatological record of modern Mars to 10 Mars years.
 - “Tracks” of active storms and a reoccurring pattern of 3 regional dust event.
 - Rapidly changing polar CO₂ snow clouds influence the polar energy balance.
 - Models confirmed the effects of water ice clouds on observed temperature patterns, showing how such clouds will affect the general circulation.
 - MRO and MAVEN data combine to show short-period atmospheric waves propagating from the lower into the upper atmosphere.
- ***Determine the nature and evolution of the geologic processes that have created and modified the Martian crust over time***
 - More CO₂ ice deposits buried in the south polar cap, cold-trapped by water ice.
 - New impact craters, some exposing clean ice in the southern mid-latitudes.
 - Ancient impacts produced extensive glass, with implications for early habitability.

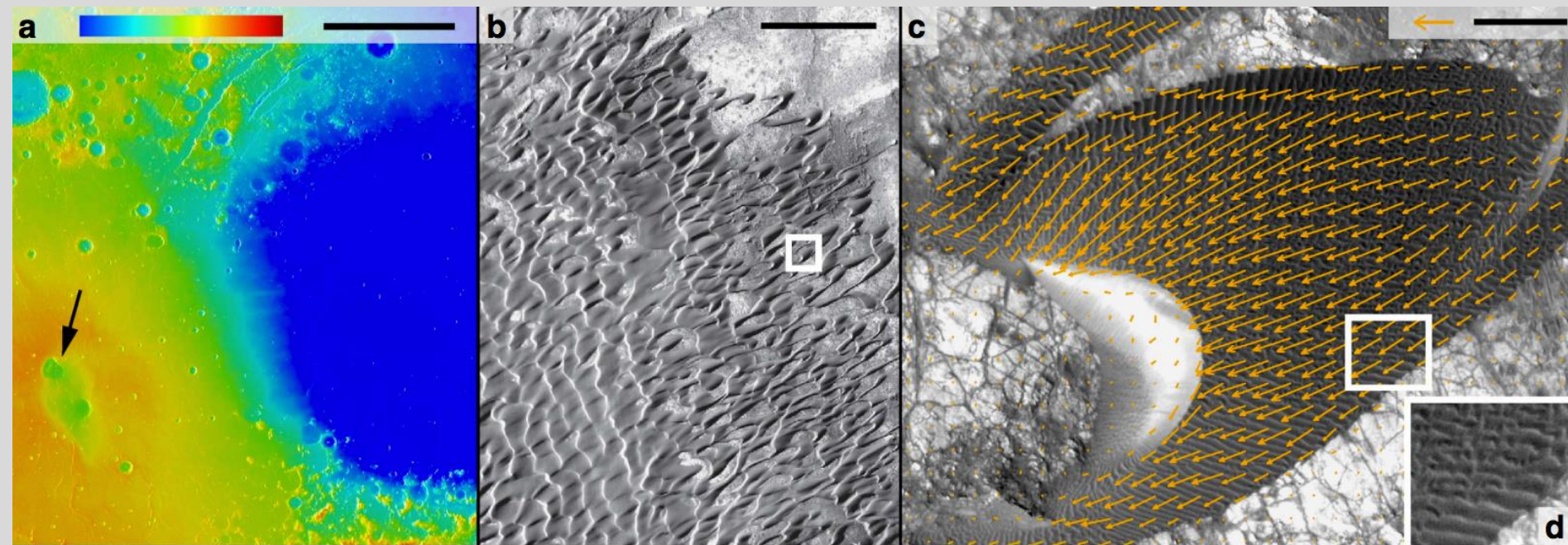
Perchlorate Salts in Recurring Slope Lineae (RSL) on Mars



(left) RSL in Horowitz crater. (center) Single-pixel CRISM spectra showing features indicative of perchlorate. (right) Perchlorate salts measured in the lab. The RSL are best fit by a mixture of phases.

- **Reference:** Ojha, L. et al. (2015). Spectral evidence for hydrated salts in Recurring Slope Lineae on Mars, *Nature Geoscience* 8, 829–832, doi:10.1038/ngeo2546.

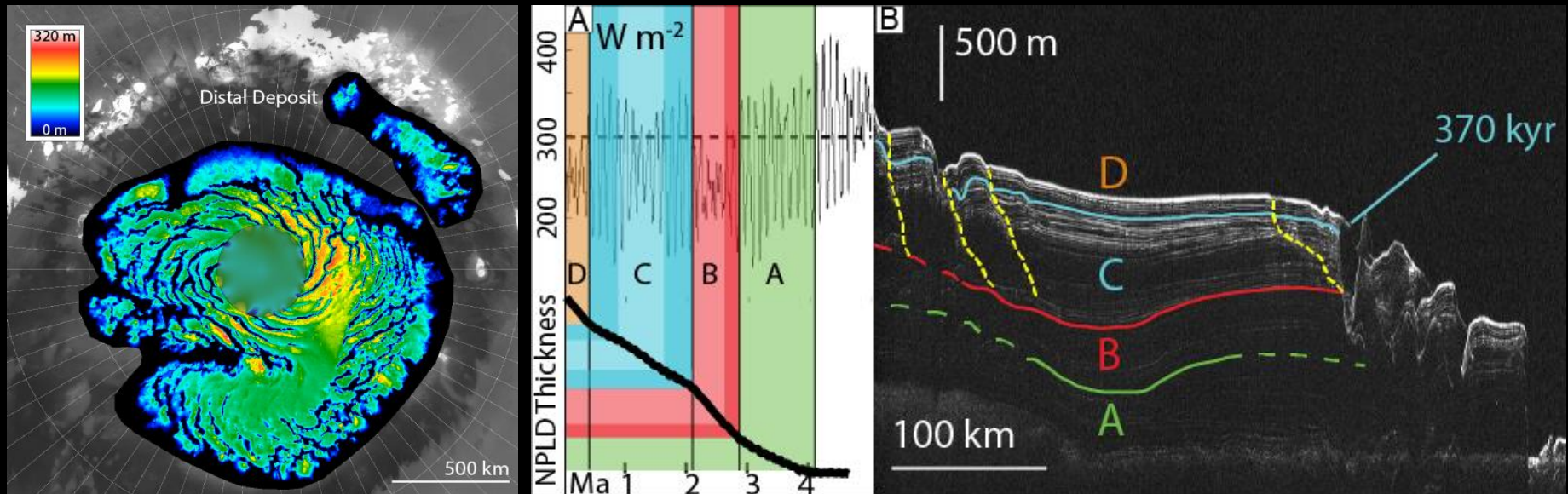
Threshold For Sand Motion on Mars Determined With HiRISE Images



- **Reference:** Ayoub et al. (2014). Threshold for sand mobility on Mars calibrated from seasonal variations of sand flux, *Nature Communications* 5, 5096, doi:10.1038/ncomms6096

An Ice Age Recorded in the Polar Deposits of Mars!

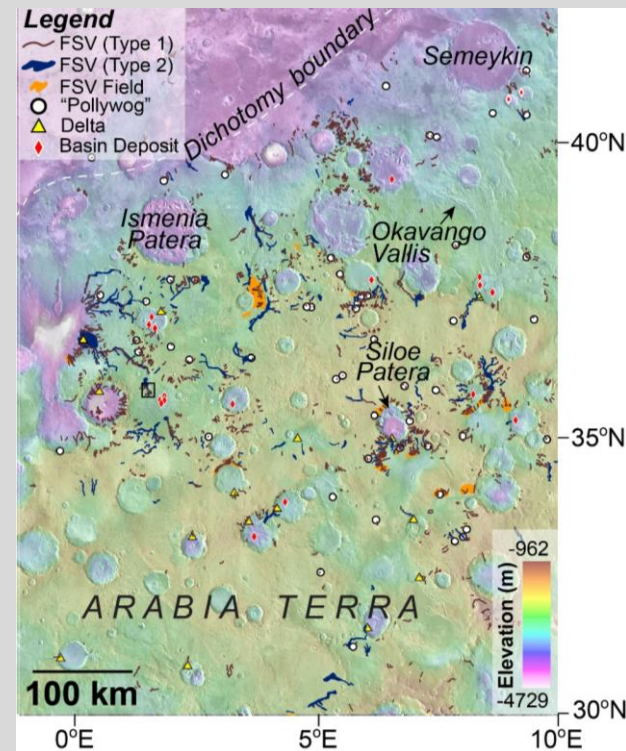
Reference: Smith et al. (2016). A record of Martian ice ages, *Science* 352 (6289), doi:10.1126/science.aad6968



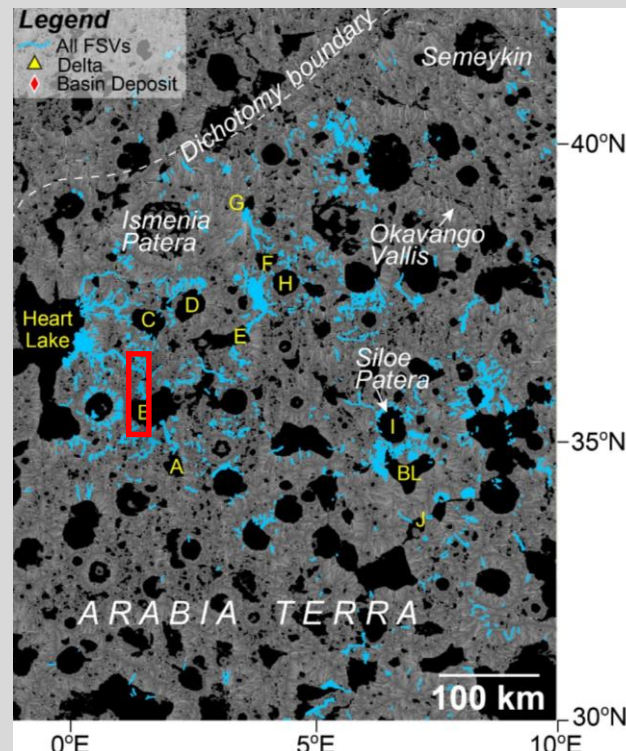
- Left: Total volume of NPLD accumulation is $\sim 80,000 \text{ km}^3$
- First attempt to date an individual stratigraphic layer gives an accumulation rate for the uppermost layers of 0.86 mm/yr , 3 times the long term average
- NPLD may have accumulated in four climatologically distinct layers
- Future work will look at lower boundaries (between A-B or B-C) to see if further and similar evidence is present

“Young” Valleys and Lakes in Northern Arabia Terra on Mars

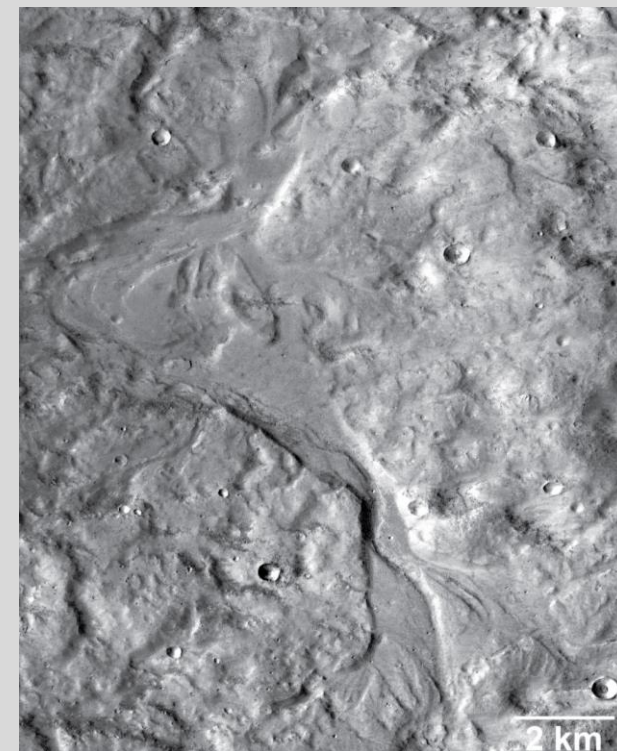
A landscape modified by water and ice: A marker of past climate (Amazonian?)



Map of Fresh Shallow Valleys (FSVs)



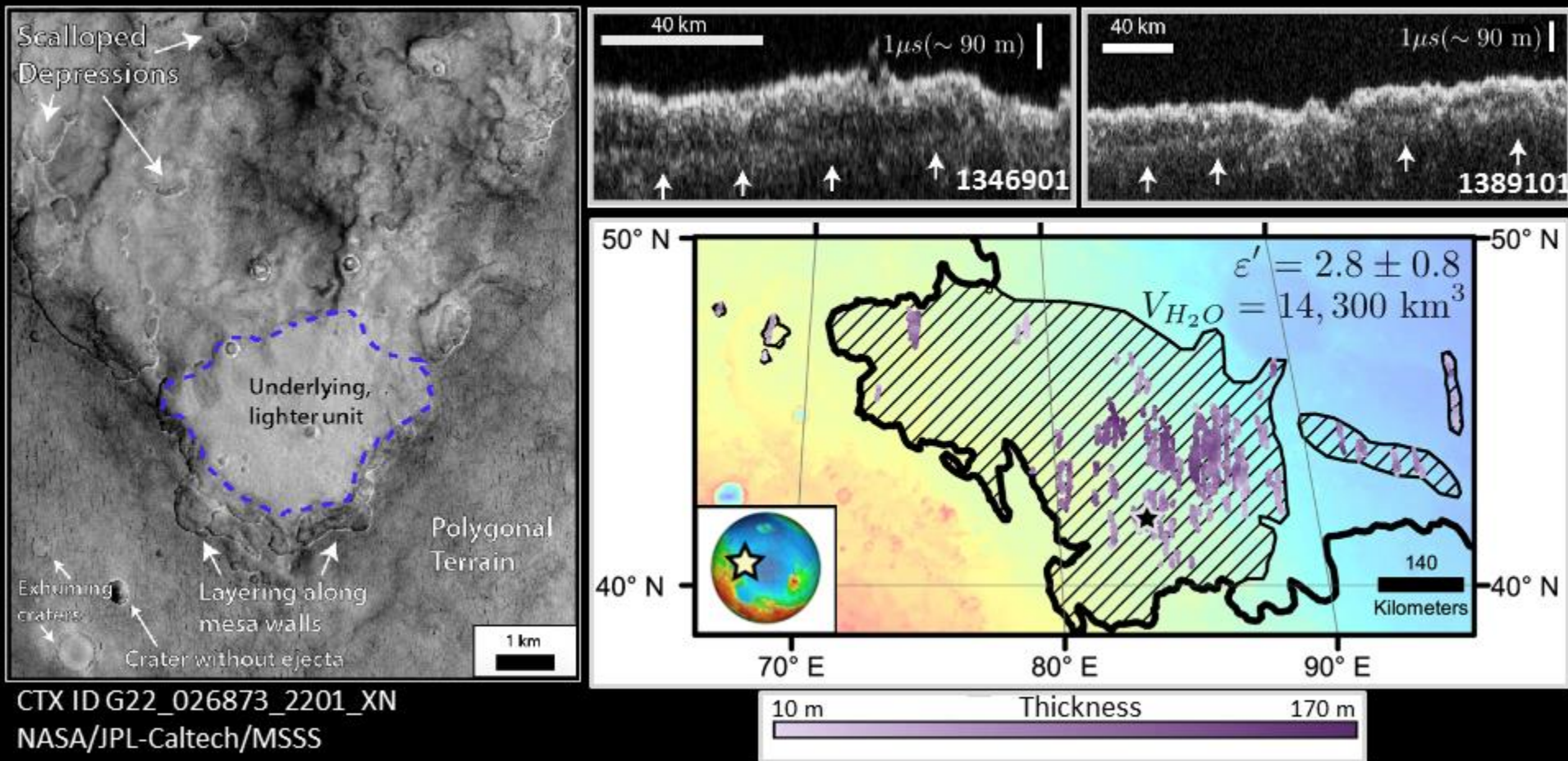
FSVs (blue) flow into and out of model-predicted paleolakes (black)



Example FSV

Reference: Wilson *et al.* (2016). A Cold-Wet Mid-Latitude Environment on Mars during the Hesperian-Amazonian Transition: Evidence from Northern Arabia Valleys and Paleolakes, *J. Geophys. Res.* (#2016JE005052R).

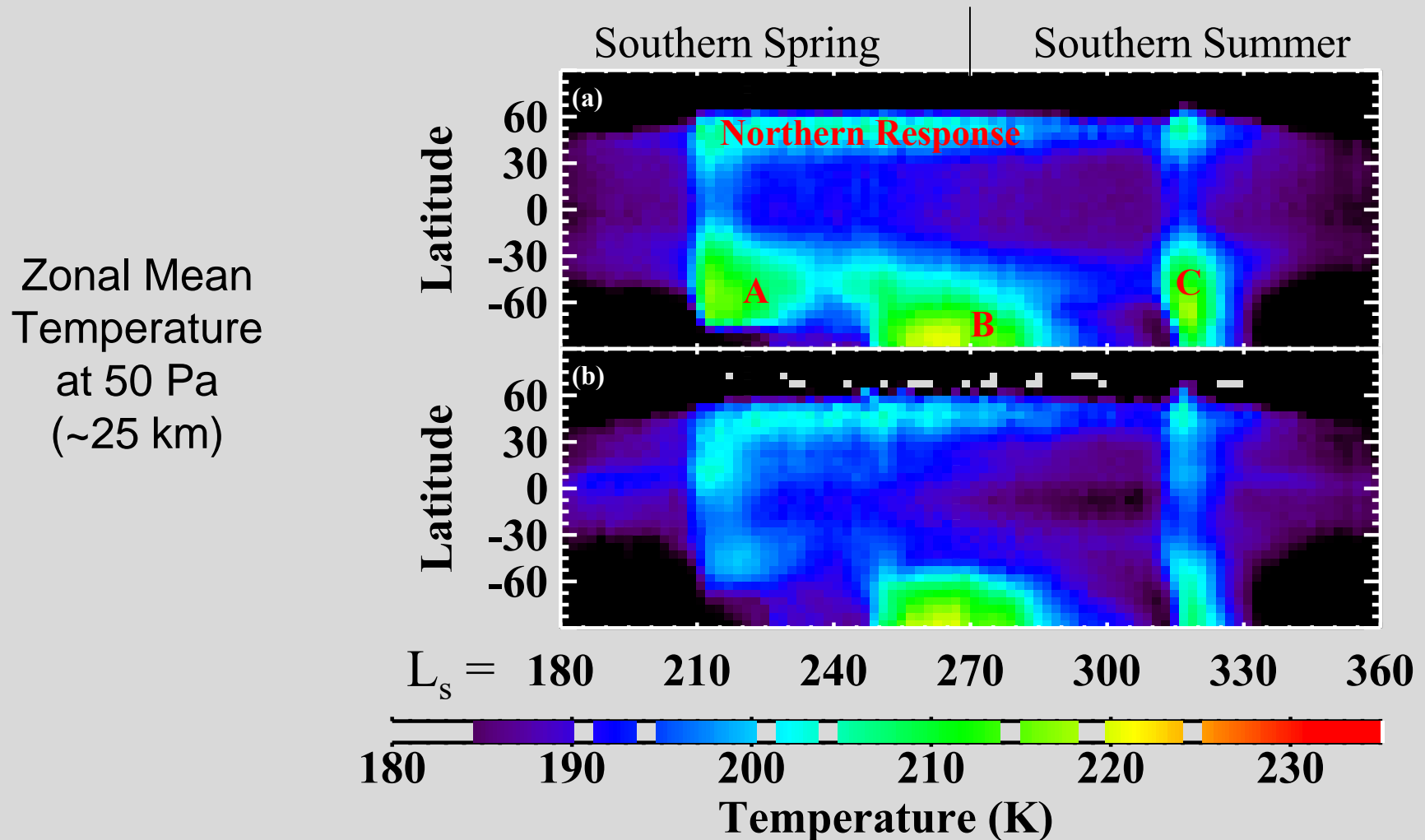
Large Volume of Subsurface Water Ice in Utopia Planitia



Reference: Stuurman *et al.* (2016). SHARAD detection and characterization of subsurface water ice deposits in Utopia Planitia, Mars, *Geophys. Res. Lett.* 43 (18), doi:10.1002/2016GL070138

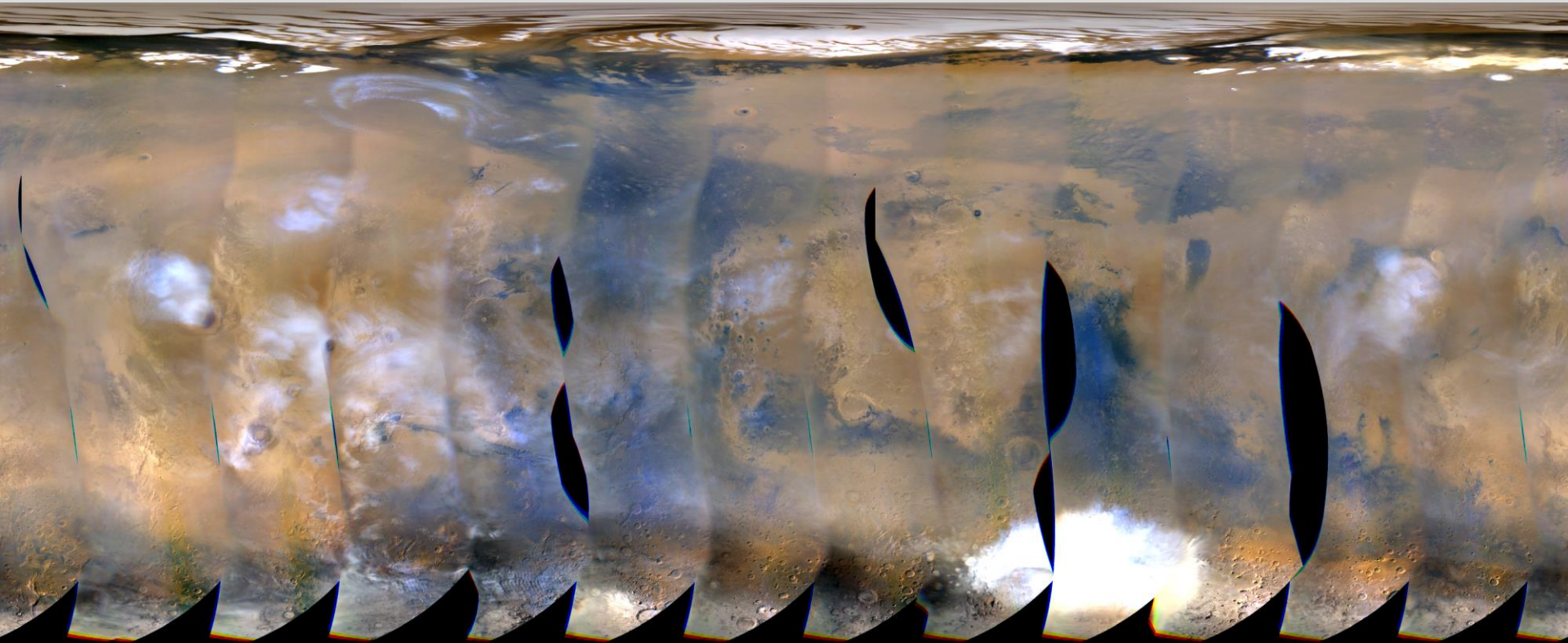
MRO Science Highlights

Three annually repeating periods of large dust events



Reference: Kass, *et al.* (2016). Interannual similarity in the Martian atmosphere during the dust storm season, *Geophys. Res. Lett.*, 43, doi: 10.1002/2016GRL068978.

Recent MARCI global weather map



March 7, 2016 ($L_S = 119.1$)

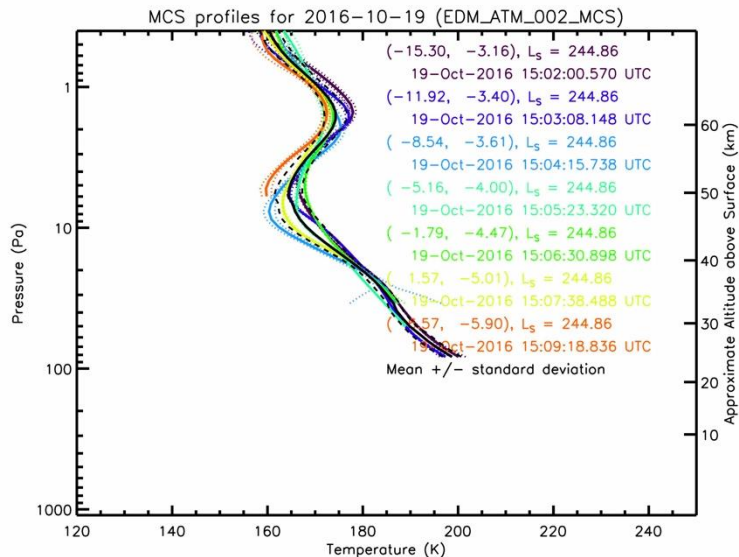
4th Extended Mission: *Mars In Transition*

Oct. 2016 – Sept. 2018

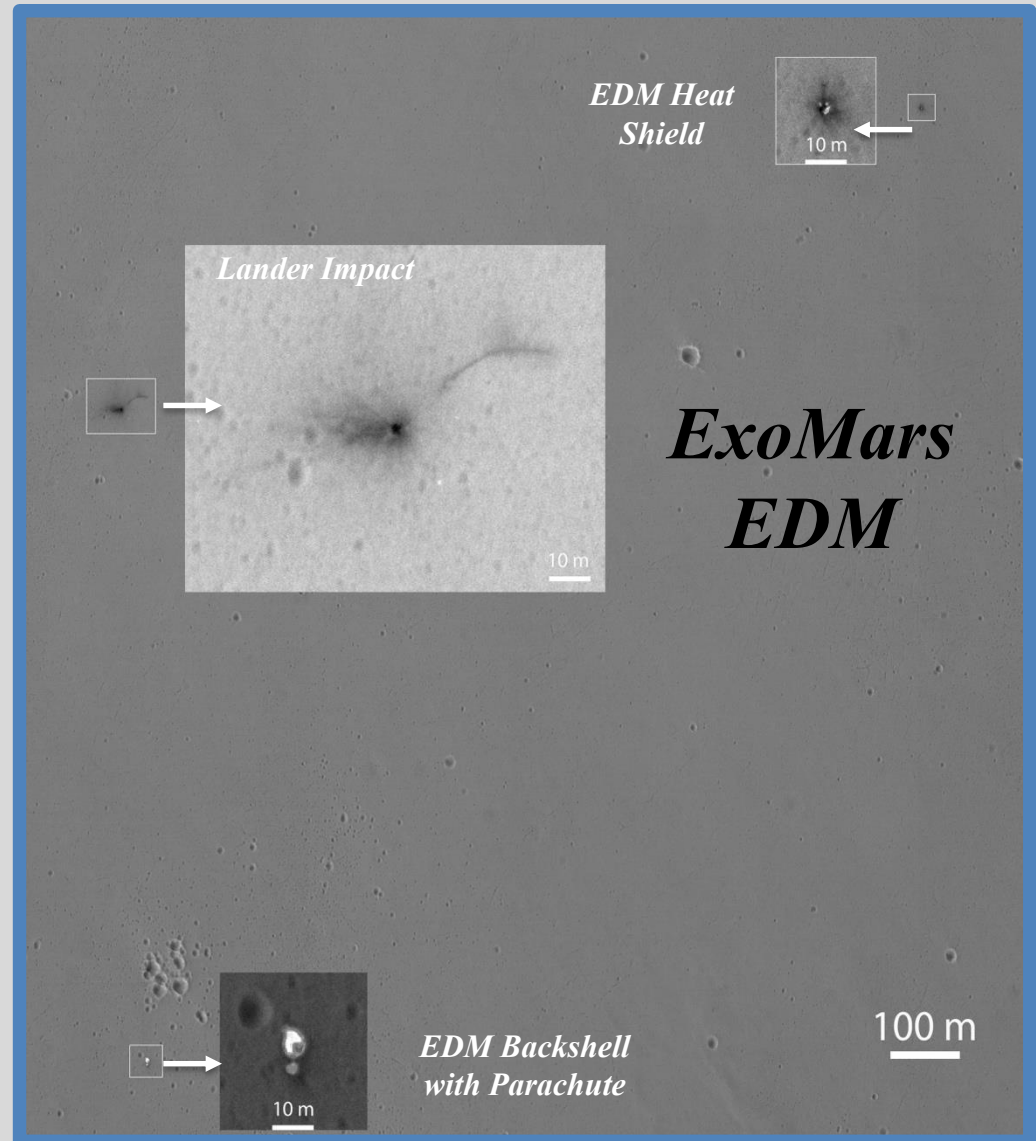
- ***Goal 1: Ancient Mars: Environmental Transitions and Habitability***
 - Focus on the formation history of younger aqueous deposits, weathered glass deposits, and older layered clays and sulfate deposits.
- ***Goal 2. Amazonian Volatiles, Volcanism, and Climate***
 - Refine our understanding of Amazonian climate signals by addressing near-surface ice deposits, polar cap layering and composition, and the potential for volcanic flows to have contributed substantial greenhouse gases to the climate.
- ***Goal 3: Modern Dynamic Mars: Surface***
 - Expand our understanding of possible liquid water on Mars today, evaluate surface change resulting from large dust events, and continue to monitor known sites while searching for new dynamic surface events indicative of ongoing transitions.
- ***Goal 4: Modern Dynamic Mars: Atmosphere and Polar Processes***
 - Observe interannual variability in a greater number of local times, via standardization of augmented local time measurements
 - Examine the influence of CO₂ snowfall on the caps and on surface changes
 - Collaborate with other missions (e.g., TGO, MAVEN) to understanding of atmospheric energy transport and chemistry, enhancing the scientific return of each mission

MRO Supports *ExoMars EDM*

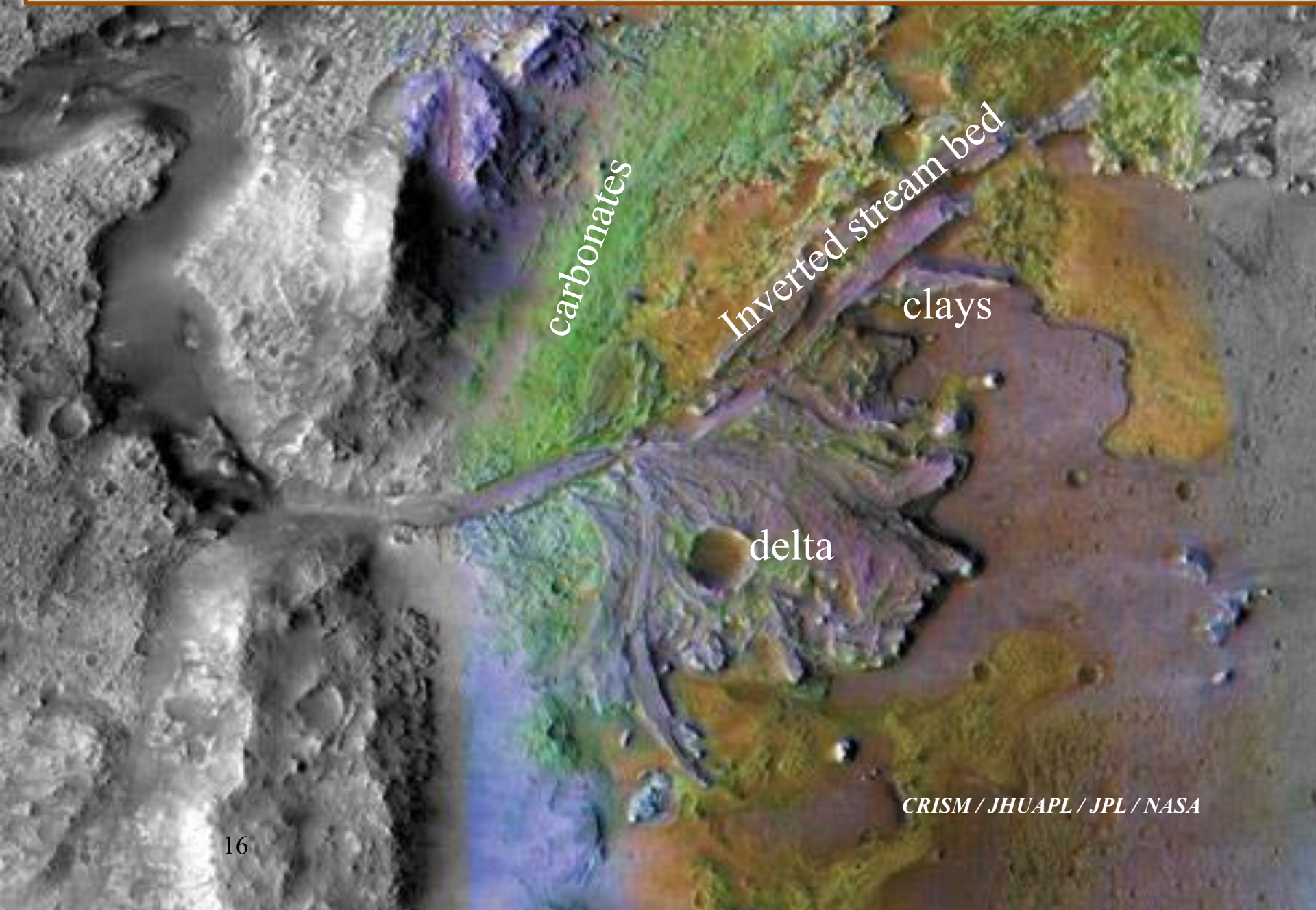
- MCS Profiles the Atmosphere near EDM Entry;
- CTX finds the impact location post-landing;
- HiRISE resolves the EDM flight elements: Lander, Back-shell, Heat Shield.



February 23, 2017



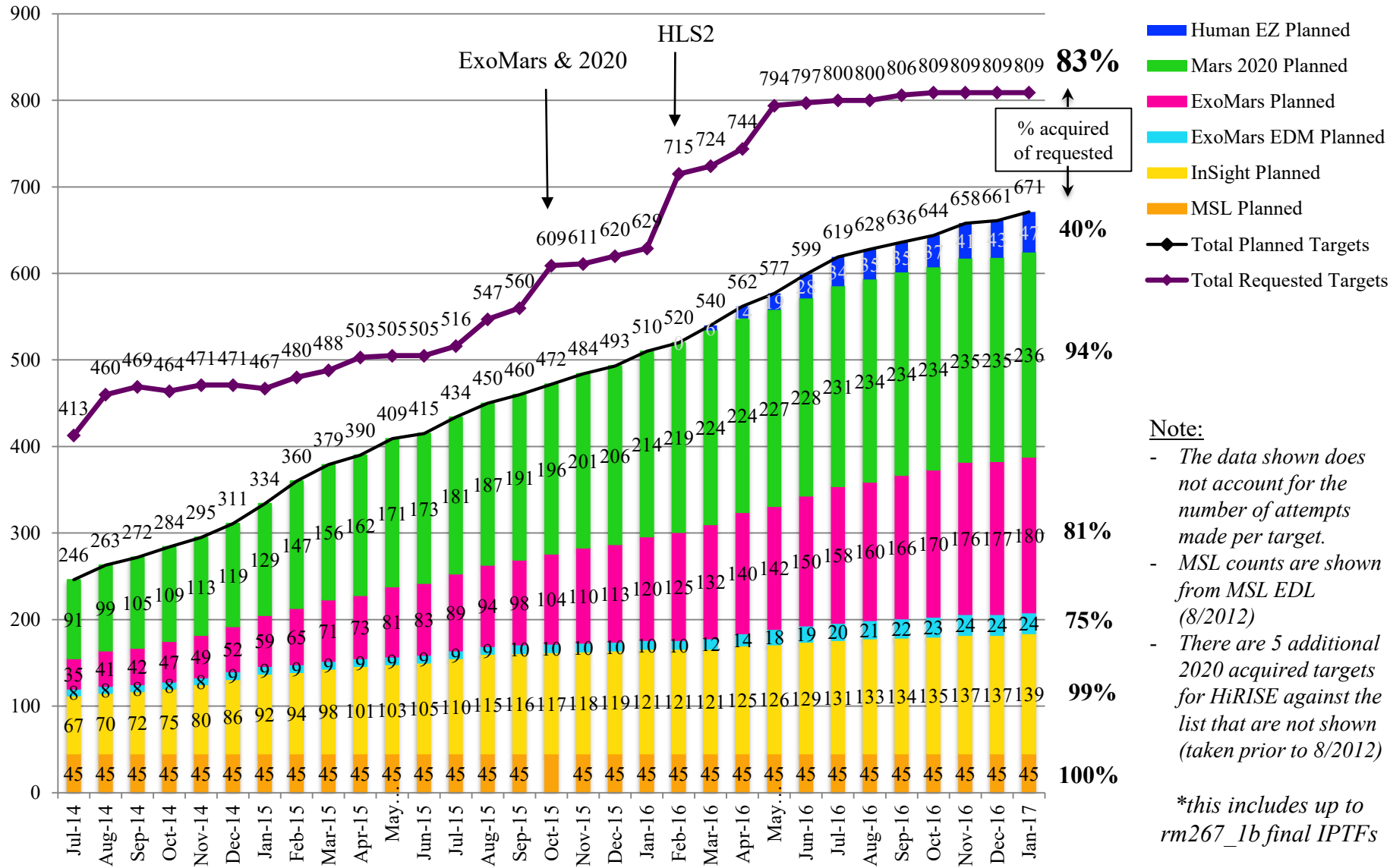
MRO & Landing Sites: Jezero Crater



CRISM / JHUAPL / JPL / NASA

Progress on Landing Sites

Number of Targets



MRO: More to Come!

MRO continues to operate nominally in its dual-purpose mission of scientific observation and programmatic support

- ***MRO is working to ensure spacecraft operability through 2023 (2020 Rover Prime Mission)***
 - All-Stellar Mode being developed to preserve IMU lifetime
 - Eclipse power management being instituted to extend battery life
 - Onboard fuel adequate for nominal operations and critical event support (2018 *InSight*, 2020 Rovers)
 - Landing site reconnaissance for *InSight*, 2020 Mars & ExoMars rovers continues
 - Preparing to support EDL and surface relay for *InSight* and Red Dragon – Continuing relay support for MER and MSL
- ***Exciting EM4 mission is in progress with all instruments operating***
 - 1 of 3 CRISM coolers continuing to yield good data in bimonthly cold cycles
 - HiRISE detector aging mitigated by warm-ups
 - MCS, MARCI, CTX, SHARAD show no signs of aging



Earth (and Moon) as seen by MRO on Nov 20th from Mars orbit.

Acquired at a range of 205 million km (~200 km/pixel)